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A knowledge-transfer-based learning framework for airspace operation complexity evaluation☆

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ABSTRACT

A sector is a component airspace whose operation is allocated to an air traffic controller. The operation complexity of a sector plays a critical role in the current Air Traffic Management system, e.g. it determines the workload volume of air traffic controllers and serves as a reliable index for airspace configuration and traffic flow management. Therefore, accurately evaluating the sector operation complexity is a problem of paramount importance in both practice and research. Due to numerous interacting factors, traditional methods based on only one single complexity indicator fail to accurately reflect the true complexity, especially when these factors are nonlinearly correlated. In light of these, the attempt to use machine learning models to mine the complex factor-complexity relationship has prevailed recently. The performance of these models however relies heavily on sufficient samples. The high cost of collecting ample data often results in a small training set, adversely impacting on the performance that these machine learning models can achieve. To overcome this problem, this paper for the first time proposes a new sector operation complexity evaluation framework based on knowledge transfer specifically for small-training-sample environment. The proposed framework is able to effectively mine knowledge hidden within the samples of the target sector, i.e. the sector undergoes evaluation, as well as other sectors, i.e. non-target sectors. Moreover, the framework can properly handle the integration between the knowledge derived from different sectors. Extensive experiments on real data of 6 sectors in China illustrate that our proposed framework can achieve promising performance on complexity evaluation when only a small training set of the target sector is available.

1. Introduction

Worldwide, the air transport industry is growing rapidly with increased movements of goods and people, creating numerous new challenges to the current Air Traffic Management (ATM) system, whose main function is to prevent collisions between aircraft and promote safe, orderly and expeditious traffic flows (Gawade and Zhang, 2016). In particular, the growing air traffic volume imposes

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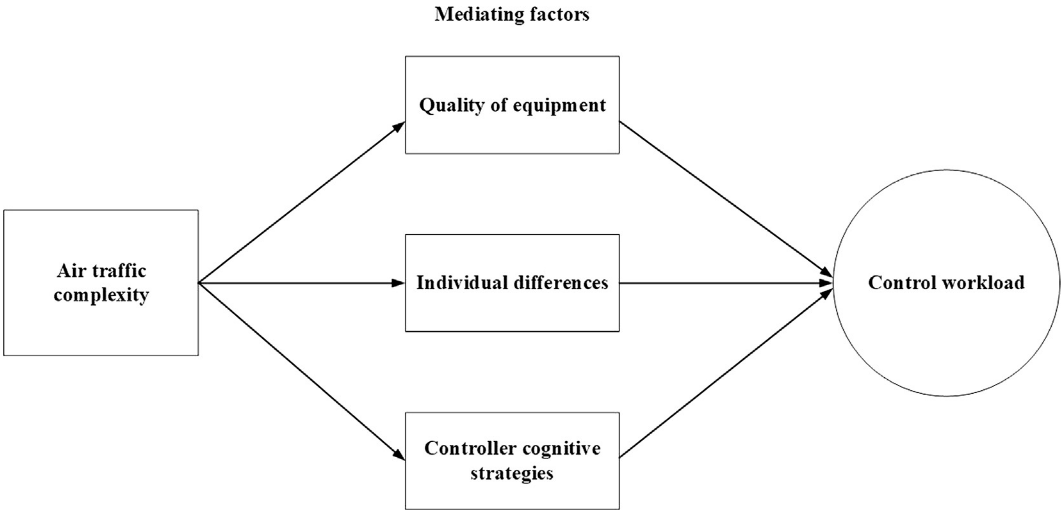

Fig. 1. Relation between air traffic complexity and control workload (Mogford et al., 1995).

high workload on air traffic controllers (ATCos). High workload often leads to operational errors (Hansen and Zhang, 2005). For instance, a study driven by National Aeronautics and Space Administration in 2010 found that the ATCos suffered from "chronic fatigue" tend to produce flight navigation errors such as allowing airplanes to fly too closely together (Orasanu et al., 2012). Furthermore, in 2014, two on-duty ATCos at the control tower of Wuhan Airport, China, fell asleep due to high workload while an aircraft was approaching (Poli, 2015). The aircraft had to go around in absence of the communication with the control tower. Apparently in these two examples, accurately evaluating ATCos' workload is the first step towards an effective ATM system that is of great significance for air traffic safety.

In the current ATM system, airspace is partitioned into small-scale volumes called air traffic control sectors (Bloem and Gupta, 2010; NATS, 2018). And one ATCo is assigned to each sector to guide the aircraft flying through it. Therefore, the configuration of airspace *de facto* facilitates the division of responsibilities among ATCo teams. In order to properly divide the responsibilities so that the traffic control workload of each sector is maintained within the limit of ATCo's capacity, it is necessary to identify a natural index that reflects sector control workload volume objectively and accurately. Here, we introduce a concept which addresses the increasing concern facing ATM practitioners—air traffic complexity (a.k.a. airspace complexity or air traffic control complexity). The concept is utilized to measure the difficulty and efforts required in managing air traffic in a safe and orderly manner (Prandini et al., 2011). For decades, research suggests the necessity of understanding the relationship between air traffic complexity and workload (Chatterji and Sridhar, 2001; Kopardekar and Magyarits, 2002; Masalonis et al., 2003). ATCo's workload is a subjective attribution. However, this attribution is highly dominated by air traffic complexity that can be evaluated objectively (Kopardekar et al., 2008). This point can be interpreted by Fig. 1 (Mogford et al., 1995), from which we can observe that control workload is linked with air traffic complexity mediating by a number of factors, among which some individual differences of ATCos play a role. Therefore, the increase in complexity results in the increase in workload (Radisic et al., 2017). Despite the relationship between complexity and workload can be individual dependent, it is reasonable to use air traffic complexity as a workload metric because it is necessary to measure the workload in an ATCo-independent fashion so as to compare the workload of sectors in a quantitative way (Rahman et al., 2015). In light of this, we apply a more specific term "sector operation complexity (SOC)" to refer to the concept of "air traffic complexity within a sector" throughout this paper. This term is adopted based on two considerations: (1) the word "sector" indicates that the complexity evaluation is targeting at a certain sector rather than a point, an air route, or other airspace elements; and (2) the word "operation" implies that the complexity metric we propose focuses on the airspace operation difficulty (control workload) rather than merely considering intrinsic complexity of traffic pattern (such as the complexity derived from traffic flow topology). Compared with the general term "air traffic complexity", "SOC" can precisely convey the exact properties of the object we want to evaluate. It is worth mentioning that, because SOC dominates the traffic control workload which is a critical quantity in ATM operation, SOC can be used as an indicator for traffic management, e.g. in dynamic airspace configuration (Tang et al., 2012) and traffic flow rearrangement (Delahaye et al., 2005). Due to SOC's significance in practice, accurately evaluating SOC becomes a prevalent research direction in the ATM domain.

Here, we review the previous works on air traffic complexity evaluation, which is a more general topic compared with SOC evaluation. Note that, the evaluation of air traffic complexity is flexible because it can be done for an arbitrary shaped airspace, and the form of evaluation output can be various, such as a continuous complexity degree, a discrete complexity level, or a "complexity map". For instance, Lee et al. proposed an input-output approach for evaluating air traffic complexity of a circular airspace (Lee et al., 2009). This approach defines complexity as "how difficult" to resolve the potential conflicts due to the presence of a fictitious new aircraft intruding the investigated airspace. The approach proposed by Prandini et al. characterizes the mid-term traffic complexity at a certain point in airspace based on the conflict risk estimation (Prandini et al., 2010), which can also be used for judging the safety of operations in airspace (Alam et al., 2013). This approach calculates the occurrence probability of multiple aircraft converging to the